Tetra Muon Cooling Ring

S. Kahn, R. Fernow

Brookhaven National Laboratory, Upton, NY 11973

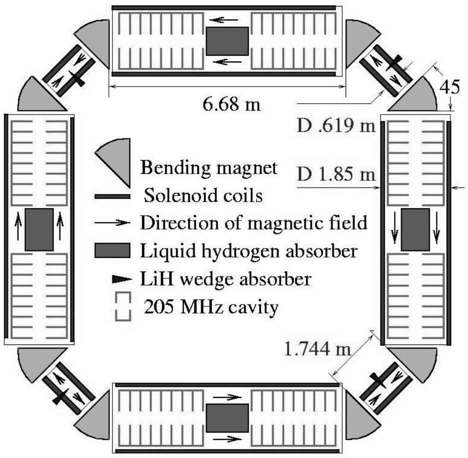
V. Balbekov, R. Raja, Z. Usubov

Fermi National Accelerator Laboratory, Batavia, IL 60510

Abstract. Recent simulations have shown that muon cooling rings can effectively reduce both longitudinal and transverse emittance. The muon collaboration is investigating several varieties of muon cooling rings. This study looks at the first of these ring cooling scenarios that was proposed by V. Balbekov. This simulation of this ring shows significant cooling in the hardedge field approximation. We discuss the status of using realistic fields in the tetra simulation.

INTRODUCTION

Muon cooling rings have shown promise in simulation studies as a technique for reducing muon beam emittance. In muon ring coolers, the muons pass through absorber material followed by acceleration repeatedly for a number of turns. This can produce cooling if there is sufficient focusing at the absorber. Currently there are three different ring coolers that are being investigated by the collaboration: 1) The Tetra four sided solenoid cooling ring, 2) the RFoFo cooling ring, and 3) dipole edge focused cooling rings. This paper will primarily discuss the simulations that have been performed for the Tetra ring. The Tetra ring, which was originally proposed by Valeri Balbekov [1], was the first of the muon cooling ring designs to show significant phase space cooling. The Tetra ring consists of long straight sections with a large solenoid magnet surrounding RF cavities and a liquid hydrogen absorber to provide transverse cooling. The field in the long solenoid varies from 2 T at the ends to 5 T in the center where the absorber is placed, so as to reduce the beta function at the absorber. The RF cavities are adjusted to replace the energy lost in the absorber. In the corner region between the two straight sections there is a short straight section with two opposite field solenoids sandwiched between two 45° dipole bend magnets. The bend magnets are combined function dipoles with a field index of 0.5 to provide focusing in both planes. Figure 1 shows the layout of the cooling ring, along with the principle parameters that describe it. The solenoid field flips sign in each of the solenoid channels, as indicated in the figure. The field flip occurs in the center of the short solenoid channel. A LiH wedge absorber is positioned near the field flip position.



Circumference	36.963 m
Nominal energy at short SS and bends	250 MeV
Bending field	1.453 T
Norm. field gradient	0.5
Max. solenoid field	5.155 T
RF frequency	205.69 MHz
Accelerating gradient	15 MeV/m
LH_2 absorber length	128 cm
LiH wedge absorber	14 cm
Grad. of energy loss	0.75 MeV/cm

FIGURE 1. Layout of the Tetra muon cooling ring and a table of the principle parameters describing the ring.

Simulations of the Tetra ring have been carried out by Balbekov using his own simulation program [2], by Fernow using ICOOL [3], and by S. Kahn, R. Raja and Z. Usubov using GEANT. The ICOOL simulation study shows significant cooling with merit factors up to 103 after 15 turns. (The merit factor, which is the muon transmission divided by the emittance reduction, is a measure used to compare various cooling schemes.) As promising as these studies have been, there are problems with the implementation. First of all, the studies that have been performed have used hardedge field descriptions, which ignore fringing fields. Secondly, there is no space between the ring elements, which could cause the solenoid and dipole fields to couple and would make it difficult to bring in RF and cryogenic services. Also there is no reasonable approach yet for injection to or extraction from the ring.

HARDEDGE MODEL

Figure 2 shows the transmission, transverse emittance, and 6D emittance as a function of turn number for this ring simulated in ICOOL using a hardedge description of the field. The figure also shows the cooling merit factor. The cooling ring lattice is highly optimized to provide this performance. In an attempt to add a 15 cm gap on each side of the wedge bend magnet, matching coils were added symmetrically to the ends of the adjacent solenoid magnets to compensate and to match into the bending magnets such that α=0. The matching coil current was varied to maximize the transmission and minimize the final emittance while keeping the focusing of the solenoids, $\int B_s^2 ds$, and the value of B_s at the absorber unchanged. Inserting this 15 cm gap reduces the transmission by 80% and increases the transverse emittance by a factor of 1.5. The longitudinal emittance is unchanged. The orientation angle of the

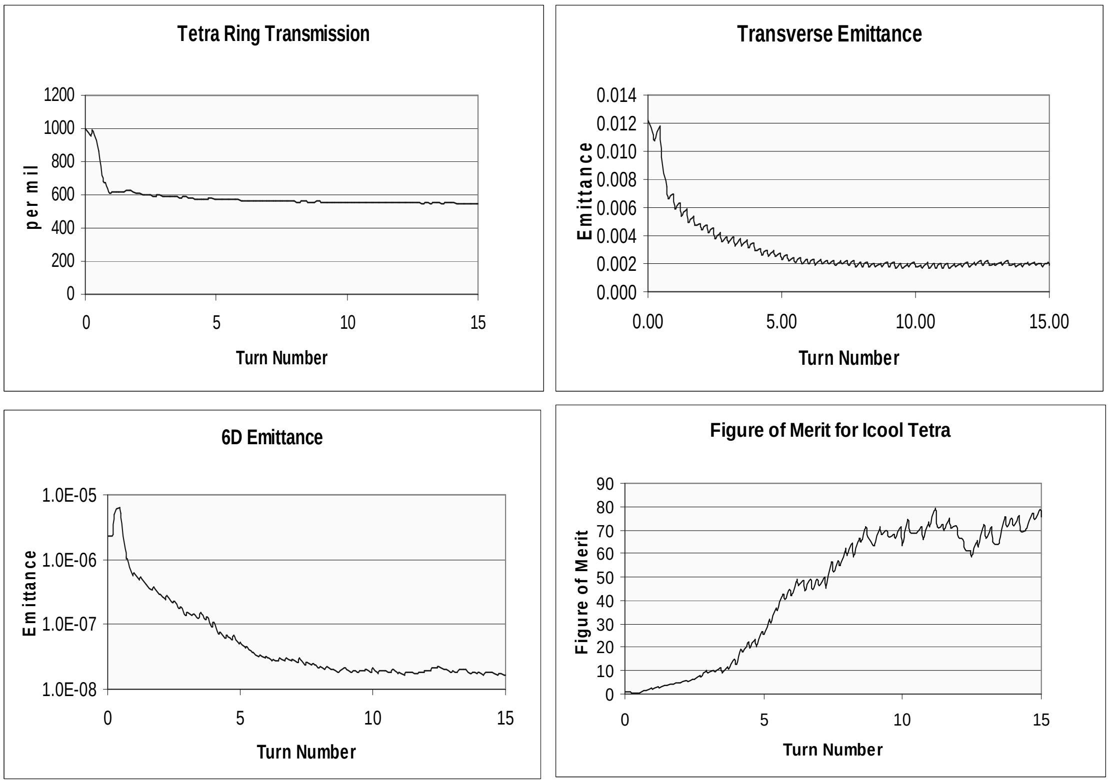


Figure 2: Transmission, transverse emittance, 6D emittance and figure of merit for the Tetra cooling ring with hardedge fields. Emittances are in meters and the transmission is given in parts per mil.

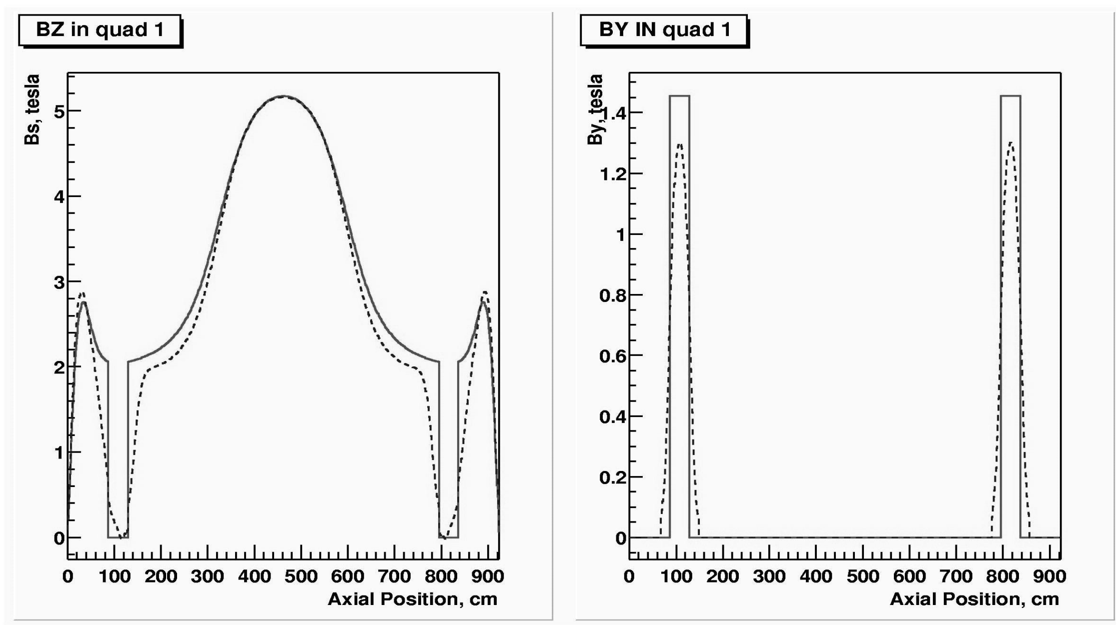


Figure 3: A comparison of a realistic field description (dotted) to the hardedge description (solid). The figure shows the axial component (left) and the vertical component (right) of the field for one quadrant of the ring.

wedge absorber should be adjusted when varying the fields, however the results are not strongly sensitive to this.

REALISTIC FIELDS

The hardedge field description does not satisfy Maxwell's equations and there is a concern that fringing fields may alter the cooling efficiency of the ring. An attempt to make a realizable design of a magnet system for the Tetra cooling ring was reported at the PAC01 Accelerator Conference [4]. In this report the 45° bend magnets are 1.45 T iron C magnets with the poles shaped to give the field index of 0.5. The pole region is highly saturated, but the magnet does provide the proper field index. Field clamps on the ends of the magnet are provided to reduce the fringing field from the dipole magnet. In order to minimize the fringe field from the large aperture of the long solenoid magnet, iron plates (with extra coils at the inner radius) are placed on the ends of the solenoid to return the flux. A similar arrangement is made for the short field flip solenoid. The resulting field from this more realistic magnet system is compared to the hardedge field in figure 3. The figure shows both the axial and the vertical component of the field for one quadrant of the tetra lattice. This field is currently being implemented in the GEANT model of this ring.

As another step toward simulating the tetra ring with realistic fields, the hard edge solenoids (with fictitious mirror plates) in the ICOOL model were replaced with an elliptic integral representation that produces a fringe field that extends into the dipole magnet region. The bend magnet in this study is still represented by the hard edge description. The solenoid fringe field in this approximation does not follow the curved reference path in the bend magnet. The emittances, transmission and merit factors obtained by replacing the hard edge solenoid by this more realistic representation remain essentially unchanged.

ACKNOWLEDGMENTS

This work was performed with the support of the US DOE under Contract No. DE-AC02-98CH10886.

REFERENCES

1. V. Balbekov et al., *Muon Ring Cooler for the MUCOOL experiment*, Proceedings 2001 Particle Accelerator Conference, Chicago, IL, 2001, pp. 3867-9.
2. V. Balbekov, *Ring Cooler Progress,* Muon Collaboration Note MUC-NOTE-246 (2002).
3. R. Fernow, *Hardedge ICOOL Model of the Balbekov Square Cooling Ring,* Muon Collaboration Note MUC-NOTE-258 (2002).
4. S. Kahn et al., *Design of a Magnet System for a Muon Cooling Ring Experiment,* Proceedings 2001 Particle Accelerator Conference, Chicago, IL, 2001, pp. 3239-41.